OCCASIONAL PAPER 118 APRIL 1951

USE OF LOW-ALTITUDE CONTINUOUS-STRIP AERIAL PHOTOGRAPHY IN FORESTRY

By
Arnold L. Mignery

SOUTHERN FOREST EXPERIMENT STATION
Chas. A. Connaughton, Director
New Orleans, La.
FOREST SERVICE, U.S. DEPT. OF AGRICULTURE

CONTENTS

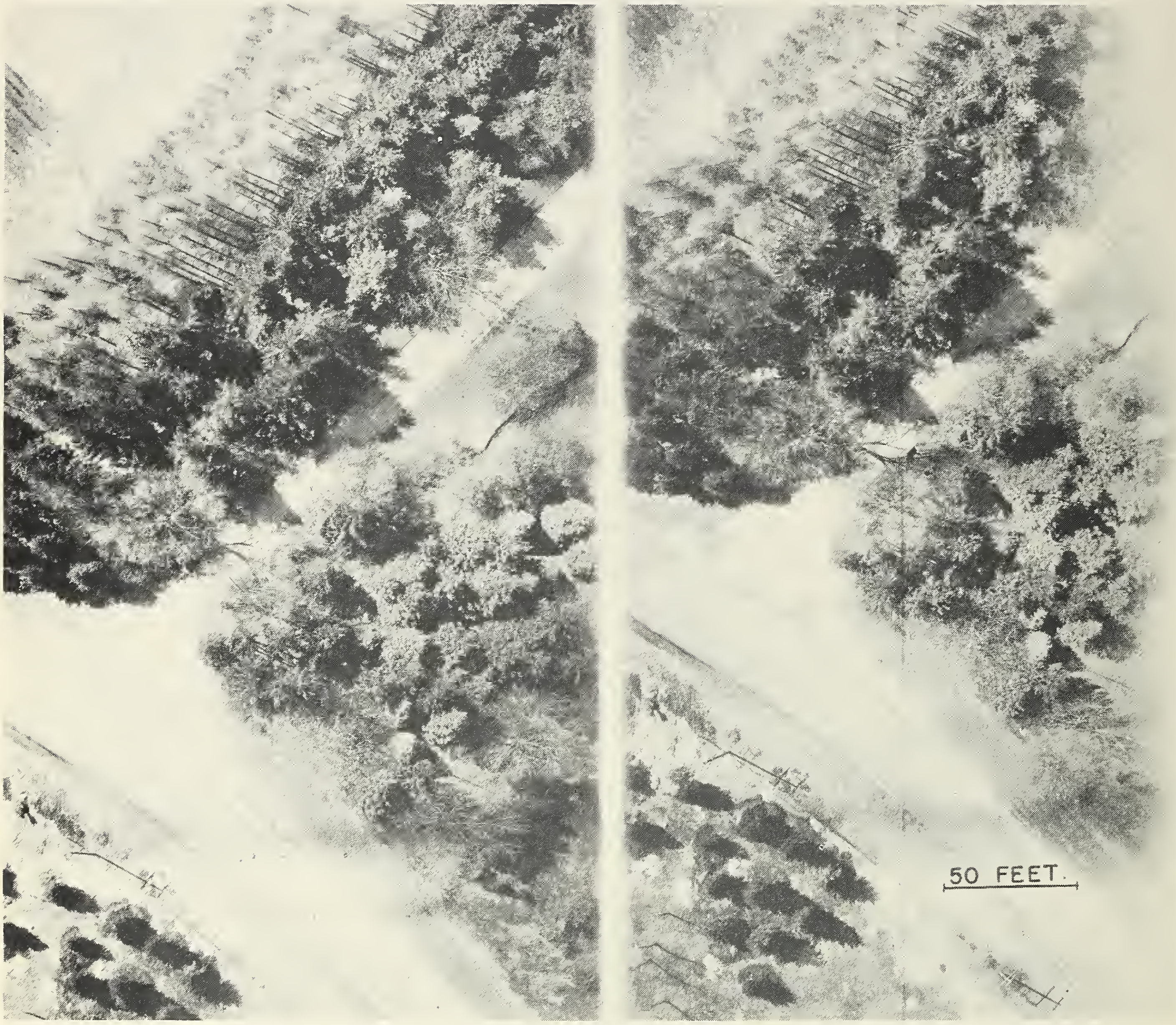

Figure 1.--Stereogram consisting of a cross section of a continuous-strip photograph. Plane's line of flight corresponds to the white line separating the pair. Scale of photograph is indicated in lower right corner. (Photo reproduced by permission of the Chicago Aerial Survey Company.)

USE OF LOW-ALTITUDE CONTINUOUS-STRIP

AERIAL PHOTOGRAPHY IN FORESTRY

By Arnold L. Mignery
Southern Forest Experiment Station

Foresters learning of the spectacular wartime achievements of continuous-strip aerial photography immediately speculated on its possible application to their own profession. This new aerial photographic technique had given measurements of water depth to within a few inches. In one instance the large-scale photographs from the Sonne' camera, as it is usually called, revealed an enemy command post when communications wire was seen leading to its carefully camouflaged position. The camera permitted fast, low-flying military aircraft to make photographs of remarkable detail and clarity to scales as large as 1/300.

To determine the feasibility of the new technique in forestry, a study was made of a photograph of an area in the second-growth upland longleaf pine type in south Alabama [1]. Results indicate that at present continuous-strip photography is not well suited to forest mensuration. It probably will never prove practical where large areas must be covered in their entirety. Where sampling suffices, however, some modifications in methods and equipment may enable the Sonne' camera to deliver pictures that contain more information than conventional aerial photographs do.

1/ The photograph used in this study was supplied through the cooperation of the U. S. Naval Air Training Center of Pensacola, Fla. The Chicago Aerial Survey Company generously provided a special stereoscopic viewer. Much valuable information was supplied by the following authorities on continuous-strip aerial photography: Prof. Robert N. Colwell, School of Forestry, University of California; Colonel George W. Goddard, U. S. Air Forces; Mr. E. W. Fuller, President, Chicago Aerial Survey Co.; Mr. Phillip S. Kistler, Seaboard Oil Company; Commander Valentine Van Keuren, U. S. Naval Photographic Interpretation Center. The writer is grateful to Prof. John Carow and Dr. S. A. Graham for their valuable criticism throughout the study, which was originally made at the School of Forestry and Conservation, University of Michigan, in partial fulfillment of requirements for the degree of Master of Forestry.

Principles of Continuous-Strip Photography

The original model of the continuous-strip aerial camera was dedeloped about 1936, by Fred Sonne' of Chicago (9) [2]. Later work by both the Army and the Navy in conjunction with the Chicago Aerial Survey Company resulted in a double lens camera which permits stereoscopic viewing of paired photo strips which are photographed side by side on the same film base.

The Sonne' camera is an adaptation of the old panorama or circuit camera. The film moves continuously past a fixed focal plane slit that is constantly open during the period of photography. The slit, although located in the focal plane, should not be confused with a shutter.

The film, which moves backward (6) with respect to the plane's forward motion, is synchronized in speed according to the following relationship (5):

$$\frac{\text{Film speed}}{\text{plane's ground speed}} = \frac{\text{focal length}}{\text{plane's altitude above ground surface}}$$

A photoelectric scanner mechanism, activated by light from the most intense reflecting surface beneath the plane, automatically maintains the film-ground speed synchronization very closely, even with changing air speeds and over rough terrain (5).

At the instant that any particular section of the film is being exposed, the image from the continuously open lens is sweeping across the open focal plane slit with the same relative speed and direction as the film (figures 2 and 3, appendix). Although both the image and the film are moving, they are stationary with respect to each other. The end result is a continuous strip of photography 9½ inches wide and up to 200 feet in length. Exposure time is a function of slit width, lens opening, and the speed at which the film is moving. Since film speed is fixed by the height and speed of the plane, only slit width and lens opening are adjustable once plane height and speed are fixed. This is not a serious limitation, since excellent photographs have been made at relative speeds up to 1,000 m. p. h. and from altitudes as low as 200 feet (2, 3, 5). Effective exposure times can be as long as 1/10 second. One special test permitted satisfactory photography forty minutes after sunset with an exposure of ¼ second (3).

Stereoscopic photography is obtained by using different lenses to expose the right and left hand halves of the slit. A small rotation of a double lens turret directs one lens forward and the other backward with respect to the slit. Thus with the camera in a vertical position

---

2/ Underscored numbers in parentheses refer to Literature Cited, page 12. Original information not otherwise acknowledged is from personal communications to the author.

the forward lens photographs an object on one-half of the film before the plane passes over it, while the rear lens records the same object again on the other half of the film after the plane has passed over. This arrangement results in two separate and parallel continuous-strip photographs on the same film base, with each strip occupying half the total film width as shown in figure 1, which is a representative cross section of black and white strip photography. The two lenses may be rotated from a zero-degree to a 20-degree stereo lens angle in control of parallax. A 5-degree angle gives normal stereoscopic values for the average observer (5). A special mirror stereoscope is used for viewing.

The photographs are made as standard black and white prints or as color transparencies.

Study Methods

The study consisted of a comparison of photographic measurements with field measurements of the identical trees and conditions shown by selected areas on the photograph.

The photograph was made in the spring of 1948. The four sections of the film that were studied represented plots slightly over $1\frac{1}{2}$ acres in size. The number of trees ($4\frac{1}{2}$ feet tall or taller) per plot ranged from 27 to 47. The photo scale varied for the four study areas, ranging from representative fractions of 1/658 to 1/771, or from one inch equals 55 feet to one inch equals 64 feet.

The photography was recorded on Kodacolor Aero Reversal film, a color transparency type. The stereo lens angle was 5 degrees. Camera focal length was 100 millimeters or 3.937 inches. For this strip, one lens was pointed vertically downward while the other pointed ahead of the airplane. The advantage of this innovation was that displacement could be measured simply by scaling inward at right angles to the center line of the vertical strip photograph.

A special mirror-type stereoscope was furnished by the Chicago Aerial Survey Company, the original manufacturers of Sonne' equipment.

Results

The impression gained from a casual examination of a continuous-strip photograph is that here must certainly be a source of precise and detailed information. The photograph, particularly when in color, is almost spectacular in the amount of qualitative detail to be found in some places. Visions of armchair forestry deluxe were shattered, however, when the photograph was closely examined and measurements were attempted. It was found that most measurements were hampered by two shortcomings in the photograph--blurring, and severe variations in the scale with slight changes in the altitude of the camera above the object. These defects will be discussed in a later section of this paper.

Field check of continuous-strip photo interpretation was made for the following variables: species identification, stem counts, height measurement, crown measurement, d.b.h. measurement, site evaluation, and distribution of reproduction.

Species identification

The writer had a general knowledge of the photographed area before the field check was made. On the basis of this knowledge, the photo allowed identification of longleaf pine (Pinus palustris), slash pine (P. caribaea), flowering dogwood (Cornus florida), magnolia (Magnolia grandiflora), and sweetbay (Magnolia virginiana). Of the shrubs, only gallberry (Ilex glabra) could be determined with some certainty. Oaks could be identified as a group only.

The field check confirmed the above determinations, but it did little to provide a reliable photo key to identification of other species in the pictures. Of the oaks, only blackjack (Quercus marilandica) had a fairly consistent color and texture pattern. Southern red oak (Q. falcata) was extremely variable in color, texture, and form, but in this stand the larger specimens could be recognized by their form and size alone. The other commonly occurring species were bluejack oak (Q. cinerea), post oak (Q. stellata), and persimmon (Diospyros virginiana). None of these had characteristic colors or patterns on the photograph. The three yellow-poplar (Liriodendron tulipifera) trees found in the photograph had a consistent color and pattern.

Where the ground was not blurred, longleaf pine reproduction over one foot in height was easily distinguished by its unique form. Slash pine reproduction was also identifiable, as was small flowering dogwood from its characteristic yellow-green color. Oak reproduction could not be identified from the pictures even with a field check.

In poorly stocked or completely open areas the grass and other small plants were usually defined sharply. If the interpreter had made field-photo comparisons in such areas, he probably could have learned to distinguish species of small plants from the photos alone. It appeared that line-intercept and transect techniques for determining percentage of species composition in ecological and range management studies might be successful.

It is entirely probable that more field comparisons with the photograph would provide clues to species identification that have been overlooked. Species identification is one of the most promising features of this new photographic technique, and the foregoing determination should by no means be considered as final with respect to this particular use of strip photography.

Stem counts

Stem counts were subject to an appreciable error, particularly on the better stocked areas. Of a total of 121 trees on three study areas,

only 99 could be distinguished on the photographs. Most of the trees missed were four inches or less in d.b.h., but there were three instances where a 10-inch longleaf pine tree was completely overlooked. Many of the "misses" were anticipated where clumps of hardwoods were involved. With pines too, it was almost certain that some crown clusters were composed of more than one tree, but the specific number could not always be determined, even with the use of the stereoscope.

If the difficulties resulting from scale variation can be resolved, continuous-strip photography may be used to prepare individual tree location maps for detailed silvicultural studies of under-stocked areas. A number of such maps were made, and the average time required to sketch a half-acre plot at an approximate 1/700 scale was 20 minutes.

Height measurements

Heights of trees were measured in three different ways: By the length of the tree shadow, by the method of displacement, and by the method of parallax difference.

The shadow method was completely unsuccessful, since the photography had been done near mid-day and shadows were too short for accurate computations. The fact that older longleaf pine crowns are often rounded further complicated such measurements. However, in some timber types shadow measurement might be the most accurate method of height measurement on these large scale photographs.

Height measurement by parallax difference and displacement was more successful, but it was not accurate enough to be used with a sampling technique. Had records of plane ground speed and film speed been available, more accurate height computations might have been made with the velocity formula (see appendix pp. 13 and 17), which automatically removes errors in altitude and film speed synchronization.

Parallax method.--The term parallax denotes displacement of one object with relation to another. In this case the displacement is that between the two images of the same object measured parallel to the line of flight. The amount of parallax or parallax difference is a measure of the height of the object.

A "floating mark" type comparator is manufactured by the Chicago Aerial Survey Company for measuring the parallax difference but was not available for the study. The Harvard parallax wedge principle was therefore adapted by the method described in the appendix, page 17.

Height determinations were made for selected trees in three of the study plots. The same trees were then measured with an Abney level. As table 1 in the appendix shows, the errors ranged widely and at random. Trees selected for these comparisons were those that offered the best chance for measurement by this method; consequently, it is unlikely that measurement of additional trees would show any increase

in accuracy. Results might have been better with the special "floating mark" comparator, but when the tree top is blurred, as it often is, accuracy would be impossible with even the best equipment.

Displacement method.--Along the outer part of the film strip some isolated trees are exposed from base to crown tip. This displacement effect is similar to the view of trees seen from a lookout tower--near the tower only the crowns can be seen, while more and more of the trunks become visible as trees farther from the tower are viewed. In the photo, limbs, crook, and even some large defects were apparent where blurring did not interfere. The number of trees so exposed was small, however, and most of them were open-grown, low-quality stems.

Since one of the stereo strips was taken with a vertical lens, displacement was conveniently measured on it by scaling distances at right angles from the strip center line to tree tops and bases. A specially made micrometer wedge reading up to 2.50 inches by 0.01-inch graduations was used. The procedure for converting these measurements to height is given on page 18 of the appendix.

The results (see table 1 in appendix) were somewhat more accurate than those of the parallax method, with the truest measurements being derived from trees whose bases and crown tips were most clearly defined. It is apparent, however, that the degree of accuracy is still far from satisfactory.

Crown measurements

The most striking single feature of the strip photographs is the sharply defined detail of some of the tree crowns. Individual needle clusters are apparent on the pines, and the new terminal growth or "candles" of the longleaf pine show with unusual clarity. In some cases the staminate cones are visible. Crown vigor can also be assessed from the foliage density, and, in this photo, color. One group of slash pines was seen to have browning foliage. The cause was normal needle cast in conjunction with new spring growth, but apparently insect infested trees with yellowing foliage could be easily spotted on color photography of this type.

Crown diameters could be accurately measured from the photos if the scale were known. Even then the height of the maximum crown dimension would have to be measured so that scale corrections might be made for crown level. For example, maximum crown width might easily be 50 feet above the tree base. With the plane at 250 deep above the tree base, there would be a 20 percent change in the scale value from tree base to point of maximum crown width. Each tree crown would therefore require a separate measurement to determine scale correction at the point of its maximum width, and, since height measurements proved to be erratic, it would be difficult to determine the height of maximum crown width.

In well-stocked stands it is sometimes difficult, even with a stereoscopic viewer, to determine individual crowns and crown tips. Near the edges of the film the extreme displacement often superimposed crowns and stems into such a jumble that stem and crown features were largely obscured or were unassignable to individual trees.

Diameter measurements

Since few trunks can be clearly seen, diameter measurements are generally impractical on present Sonne' photography. However, measurements were attempted on seven trees that were along the outer edges of the photo strip, and whose lower trunks were clearly visible.

One of the trees measured was 7 inches d.b.h. and the others ranged between 11 and 15 inches by field measurement.

A micrometer wedge 3/ reading to the nearest 0.001 inch was used to measure the d.b.h. The photographic distance from the tree base to the point representing d.b.h. varies with camera altitude and the displacement of the tree from the center line of the strip photograph. The d.b.h. point is computed from a geometric relationship similar to that used in measuring tree heights by displacement (see appendix, page 19).

Computed diameters ranged from 16 to 62 percent greater than the corresponding field measurements. The most probable source of error is the usual tendency for the ground zone to be slightly blurred by image movement resulting from mis-synchronization of film speed; this would result in measurements larger than the true ones.

Site evaluation

Aside from the fact that it covers only a limited area, Sonne' photography offers distinct advantages over conventional aerial photography for site evaluation. All of the principal criteria (10)--topography, soils and geologic formations, vegetation, and total height-crown diameter ratio--are much more evident on the large scale photographs, even when blurring and scale variations are considered.

Distribution of tree reproduction

In understocked areas where there was usually little blurring, tree reproduction and other small vegetation were seen clearly. The Sonne' camera can also be used to advantage in areas where there are few tall trees to change the film speed synchronization to that of the upper crown canopy.

3/ The wedge was Timber Survey Aid No. 2, from the Pacific Northwest Forest and Range Experiment Station, 423 U. S. Court House, Portland 5, Oregon.

No plantations are included on the film studied, but it is evident that the photographs could be used advantageously in survival counts and other studies of extensive plantings. Blurring would not occur until tree heights exceeded the limits outlined below, and excellent counts could be made on the regular pattern of a plantation.

Blurring and Scale Variation

Blurring

Correspondence with Kistler and Colonel Goddard indicates that blurring is mainly an effect of film speed synchronization. The electrical scanner picks its cycle from the strongest ground image. Thus, in a well stocked area, the light image actuating the scanner would come mainly from the crown canopy, and the film speed would be adjusted accordingly. Since the tops of trees have greater angular velocity with respect to the camera than the ground below them, the film is moving too rapidly to define clearly the lower openings that appear from time to time in a heavy canopy. Conversely, in understocked areas the main scanner impulse comes from the ground, and the tops of scattered tall trees will be blurred.

Kistler observes that the depth of focus varies with focal plane slit width and f/stop. However, he states that the clearly defined zone would average between 1/5 to 1/10 of the plane's altitude above ground. This means a sharpness zone of only 20 to 40 feet when the plane is at 200 feet. Colonel Goddard estimates approximately the same zone of sharpness. He states that "objects whose images would require a five to ten percent change in film speed to be in perfect synchronization, are recorded satisfactorily in spite of their being somewhat linearly distorted along the line of flight."

By using the relationship that

$$\frac{\text{film speed}}{\text{plane's ground speed}} = \frac{\text{focal length}}{\text{plane's altitude}}$$

it can be shown that at 200 feet above ground a plus and minus change of 10 percent in film speed with all other factors constant would give a sharpness zone ranging from 182 to 222 feet, a spread of 40 feet. If the scanner were picking its cycle from the ground only, 200 minus 182, or 18 feet, would be in the sharpness zone. If actuation of the scanner is from an intermediate crown canopy at least 18 feet above the ground, the full zone of 40 feet would be available. For the film studied the sharpness zone seems to correspond closely to these relationships. Blurring can be greatly reduced or eliminated by higher altitude flights, but this would produce smaller scale photos unless a camera with longer focal length were used.

Scale variation

In military reconnaissance with automatic film speed synchronization the altitude of the plane need not be constant provided that records are made during photography of film and plane speed. These records, when correlated with the film index numbers that are stamped at 8.15-inch intervals along the film margin, make it possible to compute photo scale at each index point. Such records were not available for the photography studied. Instead, the scale was calculated from ground measurements of distances between objects identifiable on the film.

If the airplane's altitude remains constant, topographic changes still result in large variations in scale, even over gently rolling terrain. For example, with a 100 mm focal length camera in a plane flying at 200 feet, a ground rise of 25 feet will change the photo scale from 50.8 feet per inch to 44.5 feet per inch, a 12.4 percent linear change. If sample plots were being measured, the change in area would be 23.3 percent. As has been pointed out, such changes in scale also make it very difficult to determine the true size of tree crowns from a Sonne' photograph.

If the Sonne' camera were to be used in relatively level country, numerous ground measurements would be needed for scale determination unless accurate flight records of film speed and the plane's ground speed were taken. In rugged terrain, strip photography would be ruled out, at least for large scale photography. Higher camera altitudes would reduce percentage variation in scale, but in turn scale would be reduced, diminishing the advantage of strip over conventional photography.

Further work with continuous-strip photography should be done with longer focal length cameras. Colwell points out in correspondence that such cameras would largely remedy excessive scale variation and blur as well as the excessive lateral displacement of images near the film edge. One disadvantage of longer focal lengths would be to restrict further the already narrow strip of ground covered by the photographs.

Availability and Costs of Continuous - Strip Photography

The only commercial firm that makes continuous-strip photographs at present is the Chicago Aerial Survey Company of Chicago, Illinois. This concern states that costs of Sonne' photography must be estimated for each individual job. No schedule of approximate costs is available, but the company will furnish cost estimates for specific jobs.

Since color photography has certain advantages over black and white prints, the question of the added cost of color film arises. On the basis of costs furnished by the Eastman Kodak Company (1949) the following comparisons are made for 150-foot rolls of $9\frac{1}{2}$-inch width film.

Kodacolor Aero Reversal		Infrared Aerographic	
$ 270.20	Film	$ 77.20	Film
27.02	Tax	7.72	Tax
11.80	Processing chemicals	52.50	Materials to develop and print: Estimated at 35¢ per foot
$ 309.02	Total	$ 137.42	Total

$$\frac{\$\,309.02}{150\text{ feet}} = \$2.06\text{ per foot}$$

$$\frac{\$\,137.42}{150\text{ feet}} = \$0.92\text{ per foot}$$

Since film is usually a very minor part of the costs of aerial photography, it is apparent that color film at $2.06 per foot--or slightly more than twice the cost of black and white--is not prohibitively expensive.

Conclusion

Sonne' strip photography today has limited application to forestry. Fuller states in correspondence that "it has of course the elements of ultimate accuracy but could not at present be used for measurement of tree heights in general or wood volume." Kistler also pointed out that not much accuracy should be expected without exact scale control from ground measurements.

The present short focal length camera with automatic film speed regulation can probably be used in sampling understocked forest areas and large plantations, in site evaluation, in assessing range conditions, and in ecological studies when the subject photographed is not partially obscured by a tree crown canopy and when the height of the subject does not exceed approximately 1/5 the plane's altitude above ground.

Colwell has suggested making stand volume rather than individual tree volume measurements. This approach was not investigated, but it appears to be a promising means of using the strip photographs for tree volumes.

At best, continuous-strip photographs are never likely to be practical where complete area coverage is needed, for their extremely large scale is achieved at a sacrifice of area covered per flight strip. It appears that the technique will be confined to sampling procedures which require more detailed information than that obtainable from conventional pictures.

Within these limitations, however, the development of a Sonne' camera adapted to forestry work is entirely feasible.

Colwell suggests that longer focal lengths than are used today would permit photography at the same advantageously large scales but from altitudes high enough to reduce the effect of angular velocity blurring. Latest information indicates that longer focal length cameras have been developed and used successfully, but there has been no application of this equipment to forestry. Kistler also points out that flights made with consideration for the specialized requirements of forestry might eliminate some of the present shortcomings of strip photography. For example, a great deal of blurring might be eliminated by experimenting with the focal plane slit opening to find the absolute practical minimum width.

A Sonne' camera adapted to forestry work would have certain advantages in addition to those obtaining from the large scale. For one thing, more flying weather would be available. The low plane altitudes permit photography under cloud and haze conditions which prohibit exposures from the greater altitudes required in conventional aerial photography. The greater latitude in exposure time would permit photography under adverse light conditions.

Aerial cameras with conventional type shutters have been developed which apply the Sonne' principle of compensation for image motion (2, 3). The entire film magazine moves in synchronization with ground speed during the exposure period, and then returns to normal position. Such cameras appear to hold promise for forestry work and should be investigated.

Literature Cited

(1) Colwell, Robert N.
1948. Aerial photographic interpretation of vegetation for military purposes. Photogrammetric Engin. 14: 472-81.

(2) Goddard, George W.
1949. New developments for aerial reconnaissance. Photogrammetric Engin. 15: 51-72.

(3) Katz, Amron H.
1948. Aerial photographic equipment and applications to reconnaissance. Jour. Optical Soc. America 38: 604-610.

(4) ________
1948. Air Force photography. Photogrammetric Engin. 14: 584-90.

(5) Kistler, Phillip S.
1946. Continuous-strip aerial photography. Photogrammetric Engin. 12: 219-223.

(6) Lundahl, A. C.
1948. Underwater depth determination by aerial photography. Photogrammetric Engin. 14: 454-62.

(7) Neblette, C. B.
1938. Photography, its principles and practice. Third edition. D. Van Nostrand Co., New York. 590 pp.

(8) Nowicki, Albert L.
1944. Elements of stereoscopy. In: American society of photogrammetry. Manual of photogrammetry. Prelim. ed. Pitman Publishing Corp., New York. Pp. 304-320.

(9) Snyder, C. C., and Frame, R. R.
1946. How deep is the ocean? Pop. Mechanics Mag. 85(5): 124-27, 228, 232, 236.

(10) Spurr, Stephen H.
1948. Aerial photographs in forestry. The Ronald Press Co., New York. 340 pp.

(11) ________
1945. Parallax wedge measuring devices. Photogrammetric Engin. 11: 85-89.

(12) Tewinkel, G. C.
1944. Geometry of vertical photographs. In: American society of photogrammetry. Manual of photogrammetry. Prelim. ed. Pitman Publishing Corp., New York. Pp. 256-273.

Appendix

Geometry of continuous-strip photographs

The formulae used in the interpretation of the continuous-strip photograph are dependent on the fact that a line of sight projected from the focal plane slit through either lens makes a constant angle with respect to vertical and horizontal objects as the airplane moves forward in level flight. Thus the height change per unit of parallax is constant for a given altitude and stereo lens angle. This is shown diagramatically in figures 2 and 3.

Height by parallax difference measurement

The geometric relationships shown in figure 2 are the basis for the following vertical height formulae as developed by Kistler (5).

(a). $\frac{h}{\frac{1}{2}P} = \cot a/2$

from which

(b). $h = \frac{P}{2} \cot a/2$

The following relationship also is derived:

(c). $\frac{P}{p} = \frac{H}{F}, \quad P = \frac{pH}{F}$

Substituting for P in the formula (b).

(d). $h = \frac{pH}{2F} \cot a/2$

In all the above

a = Stereo lens angle
H = Altitude of camera above datum
F = Focal length of camera
p = Difference in parallax on the photograph
P = Difference in parallax on the datum plane
h = Height of tree or other object
T = Total or absolute parallax

From figure 2 it is seen that $\cot a/2 = \frac{F}{T/2}$. Substitute this in the formula (d) to give

(e). $h = \frac{pH}{2F} \times \frac{F}{T/2}$

which reduces to

(f). $h = \frac{pH}{T}$

Formula (f) was used for parallax difference height calculations. H was known from a comparison of ground-photograph measurements and p and T were measured directly from the photograph. Results of height measurement by this method are compared with corresponding field measurements in table 1.

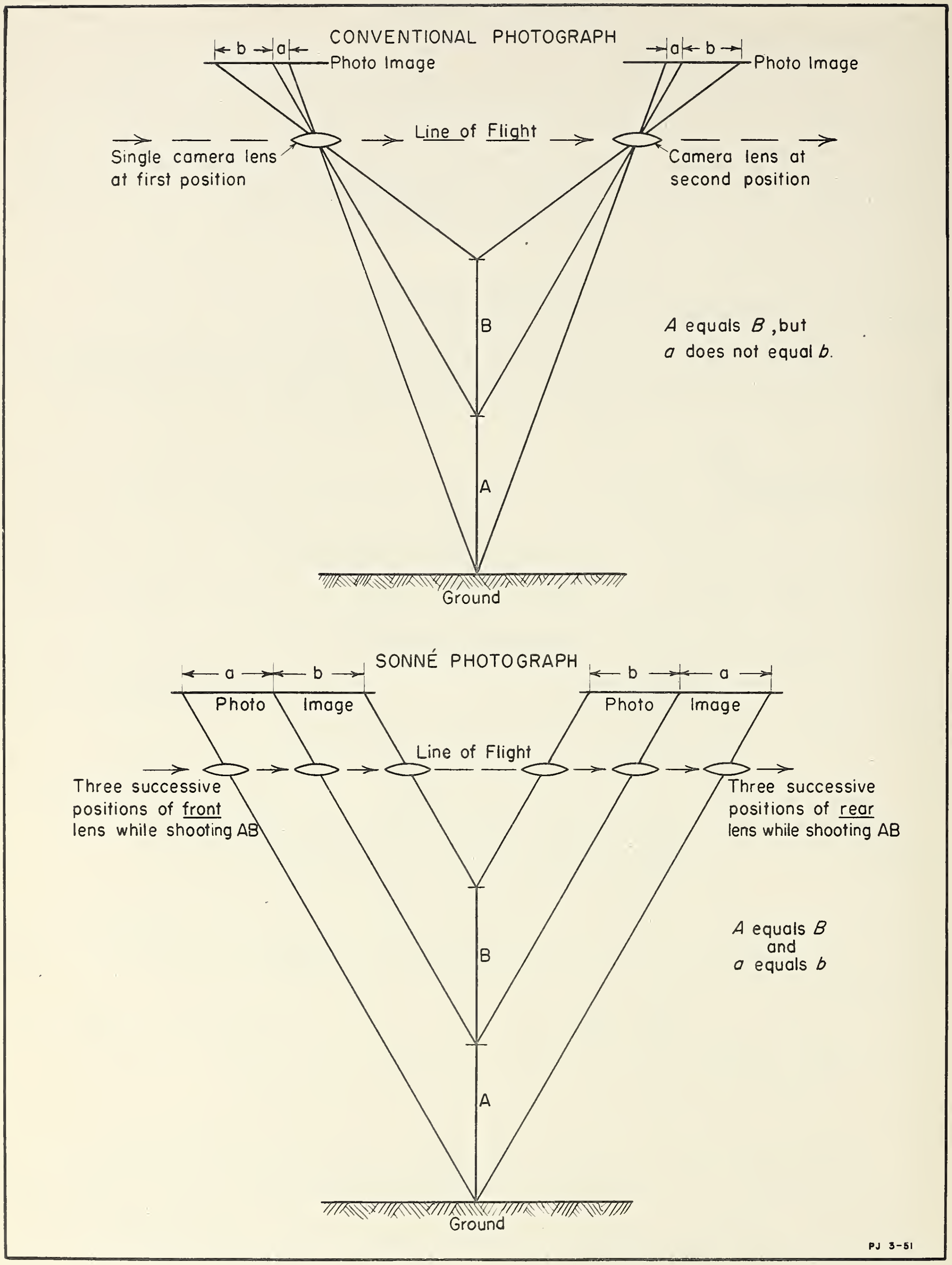

Figure 2.--Continuous-strip and conventional photographs compared schematically.

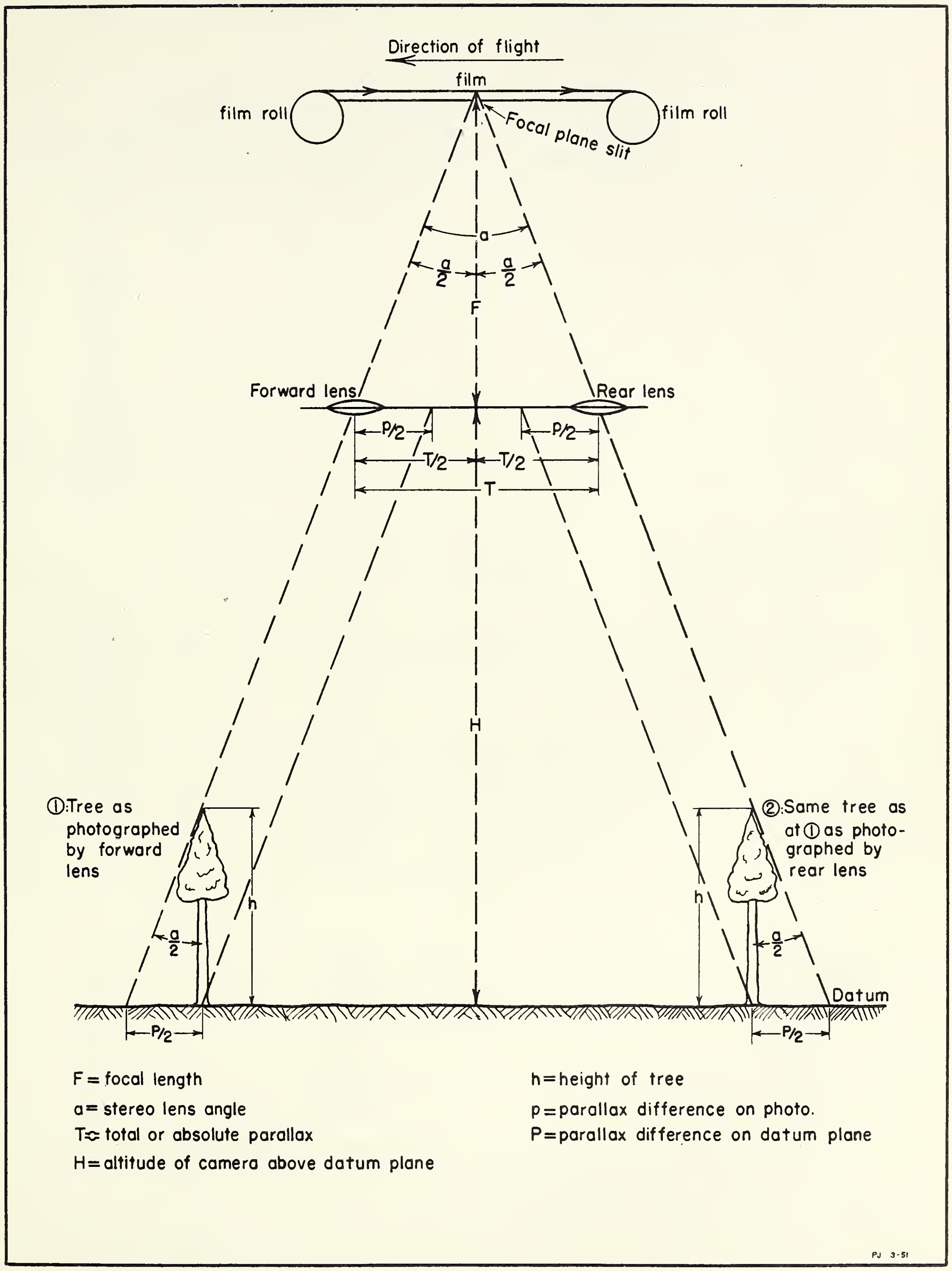

Figure 3.--Schematic diagram of Sonné camera.

Table 1.--Computed tree heights compared with field measurements (in feet)

Tree number	Height from field measurement	Computed height: Kistler's parallax difference formula	Computed height: Displacement
Area 1			
1	35	51.2	(1/)
7	65	87.4	(1/)
8	67	67.1	(1/)
15	59	58.1	(1/)
16	27	23.6	(1/)
17	(2/)	113.0	78.6
18	(2/)	82.5	83.7
20	60	95.3	76.5
24	29	34.0	17.4
25	15	12.5	25.4
Area 2			
9	68	58.2	62.0
12	67	67.6	74.5
13	62	67.6	(1/)
18	70	65.2	(1/)
21	46	41.1	48.8
24	7.3	8.9	10.5
26	8.6	7.0	11.0
30	59	57.0	(1/)
31	35	31.0	(1/)
38	49	36.1	(1/)
Area 3			
8	56	41.8	64.5
10	23	19.5	(1/)
15	62	79.5	(1/)
17	44	68.5	(1/)
28	65	78.5	76.2
31	55	76.1	49.8
32	38	53.5	45.7

1/ Measurement was impossible.
2/ No field data available.

As indicated earlier in the text, formula (f) makes no correction for errors in altitude and film speed synchronization, and these errors are reflected directly in the computations. Kistler (5) states that the only really practical parallax height measurements are made with a velocity formula:

$$\frac{dh}{dp} = \frac{Vp}{2Vf} \cot a/2$$

Where $\frac{dh}{dp}$ = height per unit of parallax

Vp = Ground speed of plane

Vf = Film speed

This formula automatically eliminates errors of altitude and synchronization. The only remaining error is the difference between air speed and actual ground speed, and this error becomes almost negligible at high airplane speeds.

Thus if special flights are made with longer focal lengths to reduce blur, and accurate film and ground speed records are kept, it may be possible to make tree height measurements of acceptable accuracy.

The Harvard parallax wedge, developed by Spurr (10, 11), was adapted for use with the continuous-strip photography by the following procedure:

The wedge was drafted on cellulose acetate material and was graduated in dots, each of which corresponded to 0.0084 inch of parallax difference. A more accurate wedge could have been made by photographic reduction, but it was found that much larger errors than those of the wedge were introduced through scale variation and blurring. Hence, the wedge used was considered satisfactory since it gave consistent readings with different operators.

In effect, the standard wedge was divided along a straight line midway between the rows of converging dots, and one of the rows was then moved forward, still in the same plane, without changing the side-wise spacing between the rows or the angle of convergence of the rows. Also, since the stereo strips are fixed, the distance between the converging lines was necessarily accommodated to the absolute parallax, which was 0.365 inch on the photography used.

The concept of absolute or total parallax and base length is unique in the case of stereoscopic strip photography. Since there is no fixed principal point as in conventional photographs, the absolute or total parallax is the distance between identical points on the strip pairs measured parallel to the line of flight (10). This is also called

the base length. A series of 32 such measurements at random points along the part of the film studied gave the mean base length or total parallax of 0.365 inch .

Height by displacement measurement

Tree height measurement by the displacement method employs the same formula used for conventional photos except that measurements are made from the center line of the strip since there is no nadir or plumb point in the sense of ordinary photographs.

As given by Spurr (10) the displacement formula is

$$\frac{d}{r} = \frac{h}{H} \text{ or } h = \frac{dH}{r}$$

where

h = Height of tree in feet
d = Length of tree image in inches
r = Distance from top of tree image to center line in inches
H = Height of the airplane above tree base in feet

All displacements were measured on the strip as photographed by the vertical lens. This made it possible to measure d and r at right angles to the center line. As pointed out previously, the usual Sonne' photograph is made with one lens pointing ahead and one lens pointing to the rear of the line of flight. Such photography would make measuring displacement more difficult since the distance r from top of the tree to the center line would be measured at an angle other than 90° from the center line. This angle would vary with the distance of the tree base from the center line.

The results of measurement by the displacement method are compared with field measurements for identical trees in table 1 of the appendix.

Diameter breast height measurement

A modification of the displacement formula was used to establish the d.b.h. point for measurement with a micrometer wedge. Figure 4 shows the geometric relationships involved (10).

From this it is seen that

$$\frac{d}{d + r'} = \frac{h}{H}$$

By algebra this gives

$$d = \frac{hr'}{H-h}$$

In this formula

h = 4.5 feet (d.b.h. point)
H = Height of the plane above the tree base
r' = Least photo distance from center line to tree base
d = Photo distance from tree base to d.b.h. point

Diameter measurements were made on the photographic strip taken by the vertical lens. As in the case of the displacement measurements for height, this made it possible to scale photo distances at right angles to the center line of the strip.

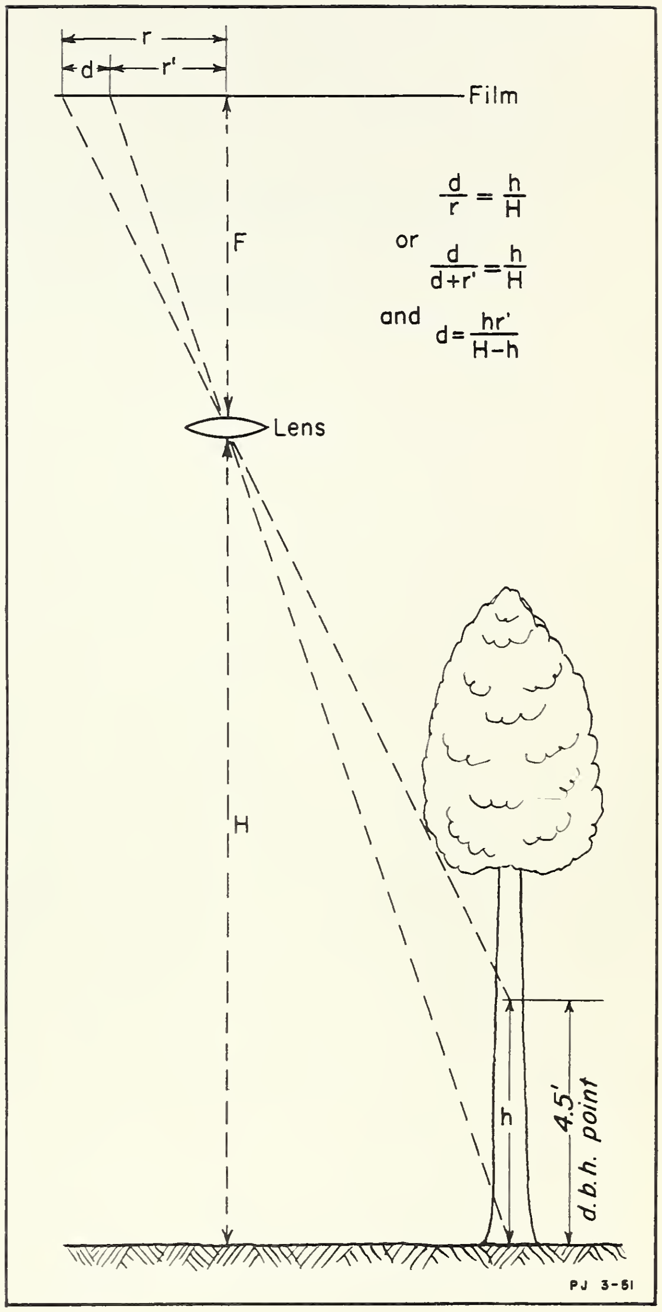

Figure 4.--Determination of d.b.h. point on film for micrometer wedge measurement.